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Droplet Combustion Experiment Drop Tower Tests Using Models of the Space Flight Apparatus

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DROPLET COMBUSTION EXPERIMENT DROP TOWER TESTS USING MODELS
OF THE SPACE FLIGHT APPARATUS

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SUMMARY

The Droplet Combustion Experiment (DCE) is an experiment that is being developed to ultimately operate in the shuttle environment (middeck or Space-lab.) The current experiment implementation is for use in the 2.2 or 5 sec drop towers at NASA Lewis Research Center. Initial results were reported in the 1986 symposium of this meeting. Since then significant progress has been made in drop tower instrumentation.

The 2.2 sec drop tower apparatus, a conceptual level model, has been improved to give more reproducible performance as well as operate over a wider range of test conditions. Some very low velocity deployments of ignited droplets have been observed.

An engineering model was built at TRW. This model will be used in the 5 sec drop tower operation to obtain science data. In addition, it was built using the flight design except for changes to accommodate the drop tower requirements. The mechanical and electrical assemblies have the same level of complexity as they will have in flight. The model was tested for functional operation and then delivered to NASA Lewis. The model was then integrated into the 5 sec drop tower. The model is currently undergoing initial operational tests prior to starting the science tests.

INTRODUCTION

The Droplet Combustion Experiment is part of series of Space Shuttle Experiments being managed by NASA Lewis. The science concepts are being developed by Professor Forman Williams of the University of California at San Diego and Professor Fredrick Dryer of Princeton University. The design, models and final flight experiment is being built by TRW Space and Technology Group of Redondo Beach, California. Checkout of concepts and precursor testing is being undertaken by NASA Lewis and Princeton personnel.

The experiment consists of studying the microgravity behavior of the burning rate, flame diameter and extinction diameter of small (about 1 to 2.5 mm) hydrocarbon fuel droplets, at or near rest with respect to its environment, at a range of oxygen mole fractions (0.18 to 0.5) and range of total pressure conditions 1/2 to 2 atm. Three fuels are being studied. They are n-decane, n-heptane and methanol. Earlier testing has shown that the first two fuels soot when burning and the soot tends to collect in a shell around the droplet. The third fuel, methanol appears to burn without forming soot.

This paper describes the engineering model recently built and its performance characteristics. Additionally, recent modifications to the 2.2 sec drop tower apparatus is described as well as some of the data obtained to date.

ENGINEERING MODEL

Upon completion of the preliminary design of the flight experiment for the Droplet Combustion Experiment in December 1986 and as a result of some encouraging feasibility tests in the 2.2 sec drop tower, where very low velocity droplet burning was observed, it was decided to design and construct a working engineering model of the flight experiment that would serve two purposes. It would verify the preliminary flight experiment designs and would also provide a test bed to obtain science data in the 5 sec drop tower facility. The data from the engineering model would provide useful data to guide the subsequent flight experiment. The flight experiment from which the model is derived is currently being considered for manifesting aboard USML-1 (Spacelab) in March 1992. Figures 1 and 2 show a schematic of the flight experiment and the engineering model. Both have a test cell in which the experiment is conducted. The burning droplet in both experiments is photographed with both a 35 mm motion picture camera, backlighted with a 1/2 mW HeNe laser beam expanded to 3 cm diameter, to photograph the shrinking droplet and a 16 mm motion picture camera with no backlight to photograph the flame surrounding the droplet. The flight experiment has gas storage bottles to change out the test cell environment. The engineering model has several unique features. Because of the 5 sec drop tower's vacuum environment, to reduce aerodynamic drag, a pressure shell was placed around the entire experiment. The pressure shell allows a near 1 atm environment around the experiment so that unwanted arcing in the high voltage electronics can be prevented. Additionally, a small video camera and recording system were installed to allow viewing of the experiment at a remote location just prior to entry into zero-gravity. Finally, the entire support structure of the engineering model was strengthened over the flight model to handle the approximately 65 g impact at the end of the experiment when the experiment is decelerated in a deep container of expanded polystyrene pellets.

Figure 3 shows a schematic of the test cell common to both experiments. The 9 in. diameter by 15 in. long cylinder has 3 windows and one electrical bulkhead. The front large window allows the expanded laser light to enter the cell as well as allows astronaut viewing in the case of the flight experiment or video viewing in the case of the engineering model. The smaller window in the back of the cell allows the 35 mm camera to view the experiment. The window on the side allows the 16 mm camera to view the test.

Within the cell is the droplet deployment mechanism, central to success of the experiment. The deployment mechanism is shown in figure 4. A fuel droplet is formed on the opposed dispersing needles from a fuel dispensing and

valve system. The computer controlled system steps the two needles apart by moving two needle carriers apart using a screw drive shaft linked to a 1.8° stepper motor. Nominally 130 steps are required to create a gap of about 1.75 mm and properly stretch a 1.25 mm droplet just prior to deployment. At deployment a cam driven by a 90° stepper motor, strikes both of the carrier assemblies, each containing a needle, and the carriers travel horizontally supported by linear roller bearings at about 50 cm/sec. The deployed droplet is then ignited by two parallel sparks issuing from the ignition electrode assemblies on either side of the droplet. The spark duration is nominally 2.5 ms with each spark delivering about 110 mJ of energy.

Each of the needles is attached to a fuel dispensing system shown in figure 5. Fuel is loaded into the system by a small tube. The fuel is stored against a diaphragm and clapper seal. About 0.5 cc of fuel can be stored in each fuel system. This amount of fuel is sufficient to generate 25 droplets in the size range 0.8 to 2.5 mm. When fuel is required a solenoid activates the clapper, allowing fuel to flow into the needles. The fuel flow rate is controlled by the strength of the spring compressing the diaphragm and small solid wire inserts inside part of the needle. The size of the droplet is controlled by the length of time the solenoid is activated. The ceramic sleeve shown stiffens the structure so that at the point of deployment large scale needle vibrations are not evident. Recent initial operational tests with the engineering model indicate needle vibrations are present, hence steps are currently being undertaken to strengthen the needle structure while attempting to minimize cross section area of the structure in the direction of needle deployment. This second condition is necessary to minimize unwanted air currents local to the droplet after it is deployed.

Figure 6 is a photograph of the existing engineering model and Figure 7 shows the interior of the engineering model test cell. Figure 8 shows some of the recent droplet dispensing test results. Plotted is droplet diameter versus droplet sequence number. The droplet diameter was found by measuring the droplet on the stretched needles and assuming the droplet was a prolate spheroid. For all of the tests shown the same fuel and same flow time was used. The results of four separate tests are shown. Solid symbols show tests where small gas bubbles were formed, open symbols show they are not. These bubbles are an unwanted artifact of a fuel valve problem recently corrected. The bubbles are very small on the order of 0.05 mm diameter. The figure shows that there are variations in the droplets formed, with a general decline in the droplet size with a decline in the amount of the fuel in the fuel system. However, for this size droplet, considering the variations between tests, when the fuel valves were refilled, as well as the decline in the droplet size as the fuel valves became depleted, the droplets were dispensed within 10 percent of the mean diameter over four tests and 30 droplets per test.

Figure 9 presents the results of stretching about 1.25 mm droplets. Plotted is the number of successful stretch steps prior to movement of the droplet off of one of the needles and completely onto the remaining needle versus the droplet sequence number. This data was gathered in conjunction with the data obtained in tests number 3 and 4 in figure 8. The tests were conducted by first growing the droplets on the opposed needles and beginning the stretch in an automated manner of the first 115 steps in test number 3 and 117 steps in test number 4. Then, every five droplets, this droplet was measured to determine its size. Finally, each droplet was again stretched manually in

units of 5 steps for test number 3 and 3 steps for the test number 4 until the droplet separated from either of the needles. Each step resulted in widening the gap between the needles by about 1.15×10^{-2} mm. The needles were initially about 0.29 mm apart. The plot shows the sensitivity of the amount of stretch to small droplet size variations caused by the decline in the fuel supply. It has been observed for this size droplet that the larger the droplet stretch the better the final droplet deployment velocity.

2.2 SEC TEST APPARATUS

The 2.2 Sec Test apparatus was originally developed to test the feasibility of the concept of using opposed needles to deploy droplets in microgravity with near zero net velocity. The apparatus also provided a test bed to examine the feasibility of igniting droplets using a parallel spark method in an attempt to minimize net momentum to the droplet from the sparks. Subsequent testing verified that both of these concepts did indeed provide for burning droplets with velocities well below 1 cm/sec.

Attention turned from feasibility issues to providing as much science data as possible with the 2.2 sec drop tower apparatus. Accordingly, the apparatus was modified as shown in figure 10. A pressure vessel was installed around the test apparatus in place of a clear plastic box used in the earlier feasibility studies. Additionally, the magnification of the camera system was increased by a factor of 1.6. Finally, as shown in figure 11, all of the equipment necessary to the growth, stretching, deployment of droplets as well as the ignition system and electrode retraction system were mounted onto a single plate for insertion into the pressure vessel. The 2.2 sec drop tower experiment employs optical scanners, devices which move radially, to move the needles apart. These devices operated galvanometrically, as opposed to screw thread or cams operated by stepper motors, as is used in the engineering model and the proposed flight experiment. The entire experiment is placed in a drag shield for the actual microgravity test. By doing this, the experiment falls 9 in. relative to the drag shield, while the drag shield is falling the length of the drop tower and therefore assures a low gravity environment at or below 10^{-5} earth normal.

Some of the preliminary results of testing in the new apparatus are compared and contrasted with earlier data obtained in the plastic enclosure. All of the data presented here was analyzed on a device which backlight and magnified each film frame so that a cursor linked to a computer could, when properly placed on the image, record the location of each edge of the droplet. This method can produce results dependent on the operator taking the data since the location of the droplet edge requires judgment. The data presented here is based on two orthogonal droplet diameters for each film frame. Princeton University has recently developed a method whereby the film image is transferred to a video image and a computer analysis of each pixel of data is evaluated to consistently find the edge of the droplet and find a true average area averaged droplet diameter. The present test results indicate that for the decane fuel tested, no apparent effect of enclosure type can be seen on the burning rate data. Additionally, the data seems to verify earlier classical models of the phenomenon that oxygen concentration strongly affects the burning rate and that pressure effects more weakly effect burning rate than does oxygen concentration.

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4. Choi, M.Y., Dryer, F.L., Haggard, J.B., and Brace, M.H., "The Burning Behavior of Methanol Droplets in Humid Air," Presented at the Eastern States Sectional Meeting of the Combustion Institute, Dec. 1988.

TABLE I. - PRELIMINARY MICROGRAVITY BURNING RATE CONSTANTS

Run	Initial diameter, mm	Pressure, atm	Mole % oxygen in N ₂	Time, sec	Kb burn rate constant	Droplet velocity, mm/sec
Tests conducted in a lab air close box ^a						
1	1.01	1.	21	1.00	0.41	1.7
2	1.04	1.	21	1.50	.56	3.1
3	.95	1.	21	.80	.67	6.8
4	1.00	1.	21	1.23	.47	5.2
5	1.07	1.	21	.93	.69	3.3
6	1.20	1.	21	.75	.33	4.3
Tests conducted in a pressure vessel						
7	0.98	1.	21	1.21	0.60	4.6
8	.82	1.	50	.40	1.00	6.5
9	1.09	.5	50	.60	1.06	9.5
10	.99	1.25	50	.51	.88	9.4
11	.79	2.	50	.68	1.10	8.3

^aTests reported earlier in IAF paper # IAF 87-403, Brighton, England 1987.

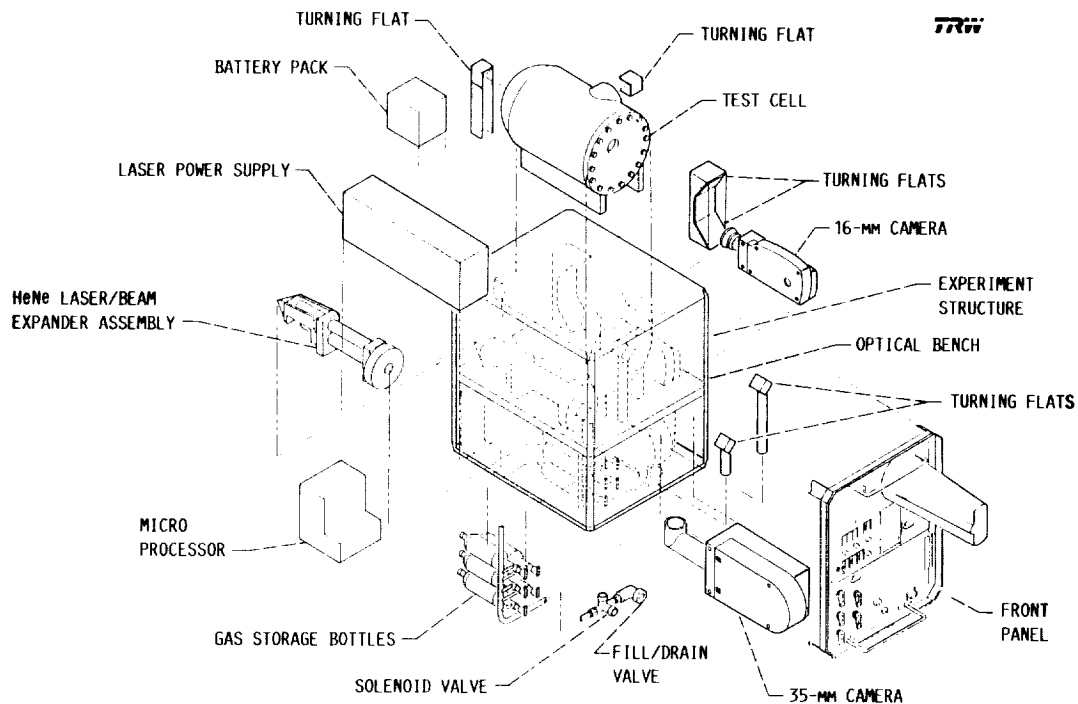


FIGURE 1. - DROPLET COMBUSTION FLIGHT EXPERIMENT.

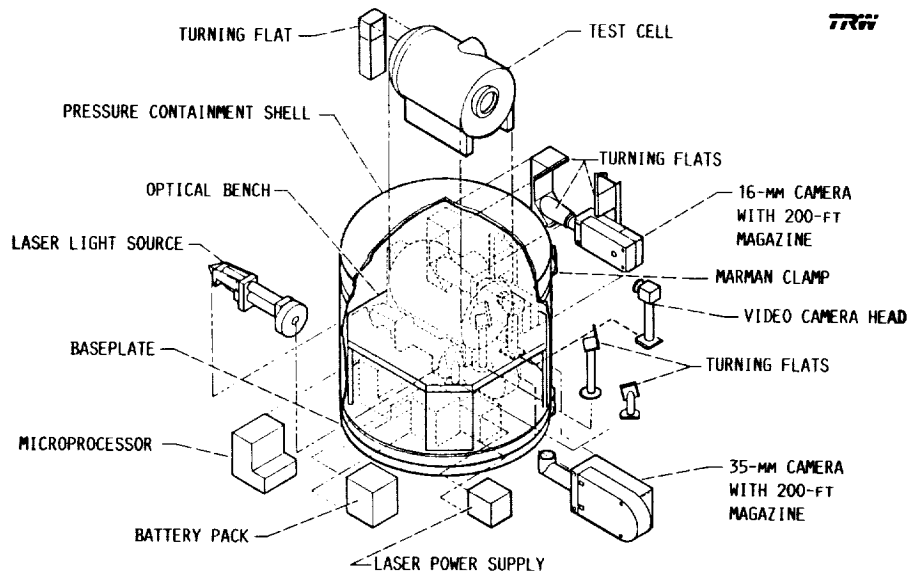


FIGURE 2. - DROPLET COMBUSTION ENGINEERING MODEL.

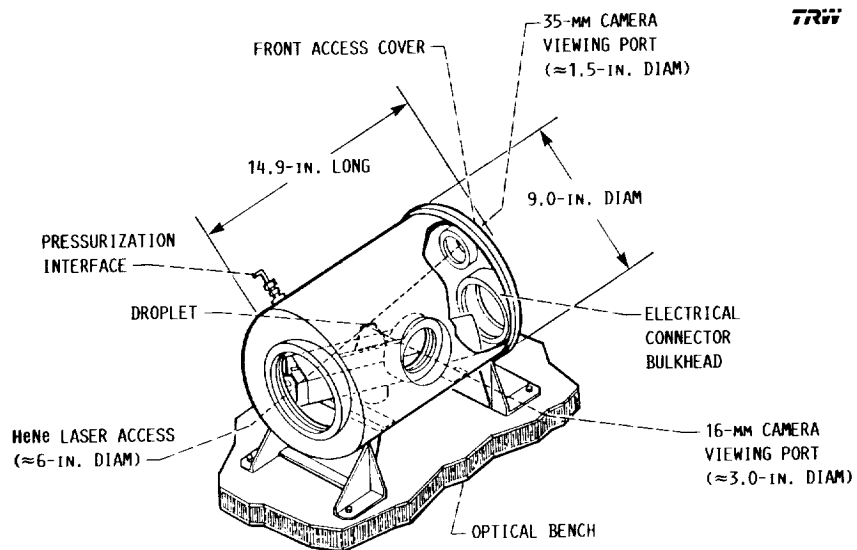


FIGURE 3. - EXPERIMENT TEST CELL LAYOUT.

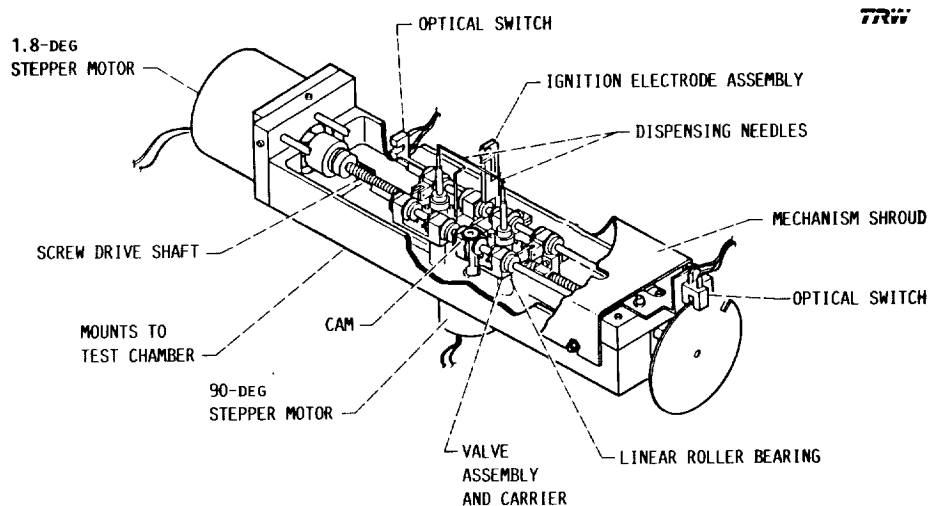


FIGURE 4. - EXPERIMENT DISPENSING, DEPLOYMENT, AND IGNITION MECHANISM.

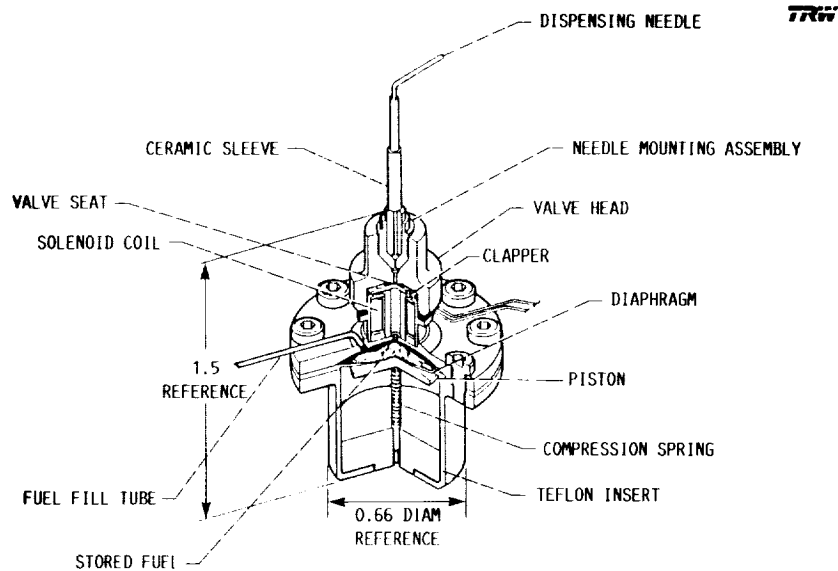


FIGURE 5. - EXPERIMENT FUEL DISPENSING VALVE.

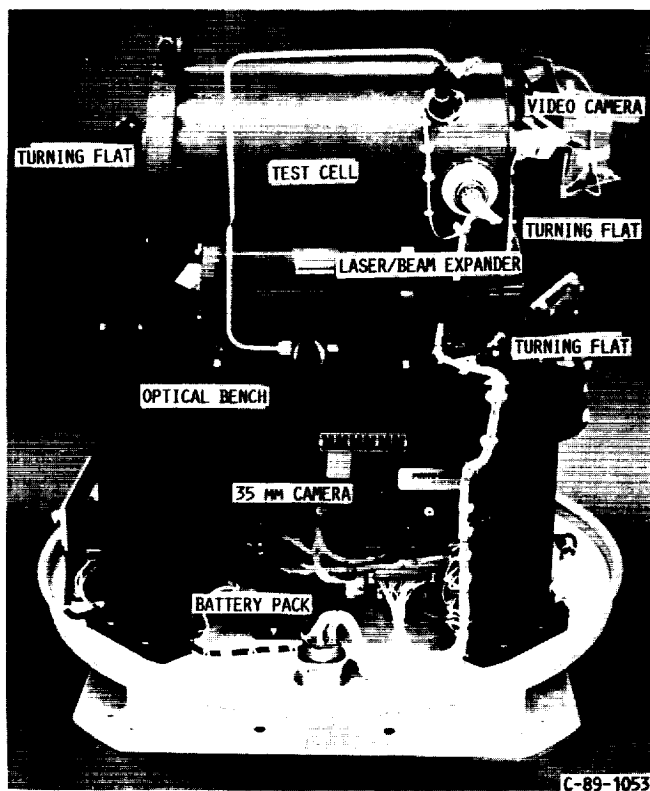


FIGURE 6. - PHOTOGRAPH OF THE ENGINEERING MODEL.

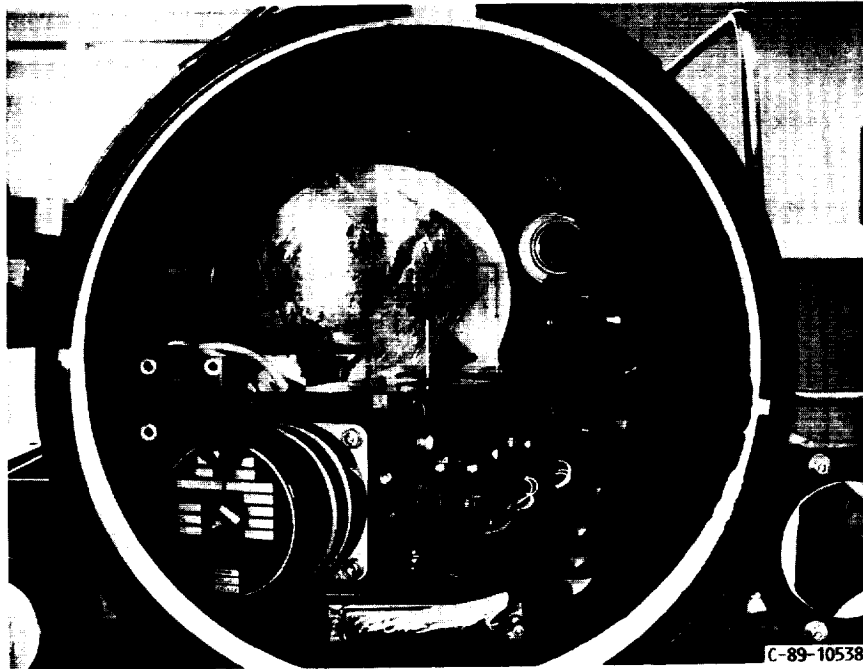


FIGURE 7. - PHOTOGRAPH OF THE INTERIOR OF THE ENGINEERING MODEL.

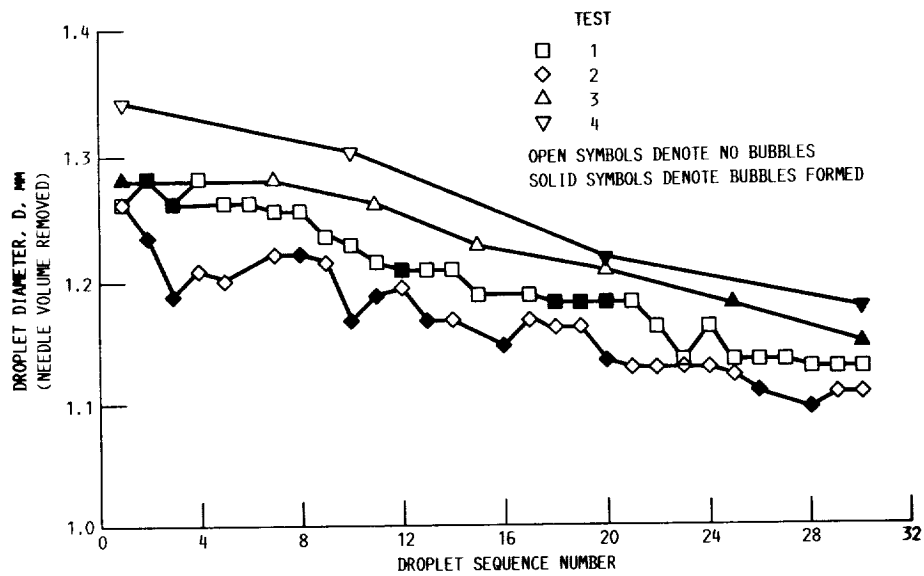


FIGURE 8. - DROPLET DISPENSING TEST RESULTS.

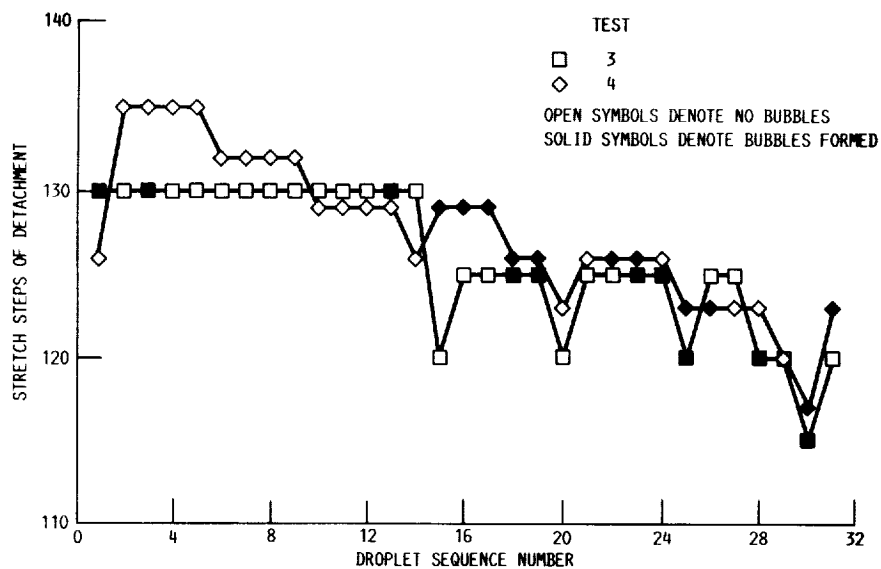


FIGURE 9. - DROPLET STRETCHING TEST RESULTS.



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FIGURE 10. - 2.2-SECOND DROP TOWER SCIENCE RIG.



FIGURE 11. - SCIENCE RIG DISPENSING, DEPLOYMENT, AND IGNITION MECHANISMS.

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